



Modeling polarized radiation for CLARREO inter-calibration applications

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- Correction of measurement errors caused by polarization
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Introduction

1. Radiation climatology requires highly accurate radiation data.
2. Instruments whose sensors are not totally depolarized may have significant errors in measured radiance due to the polarized incident radiation.
3. Accurate inter-calibration of CLARREO and other instruments requires the measurement errors due to polarization to be corrected in advance.
4. Satellite measurements of the polarization of radiation are limited by incidence and viewing geometries and working wavelengths.
5. To make high-spectral lookup tables of polarization dependence model (PDM), modeling of the polarization of radiation is needed.

Polarization fundamentals

Any arbitrarily polarized incoherent radiation can be represented by the linear sum of an unpolarized part and a 100% polarized part as

$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} I - \sqrt{Q^2 + U^2 + V^2} \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \sqrt{Q^2 + U^2 + V^2} \\ Q \\ U \\ V \end{bmatrix}$$

$$I_{pol} = \sqrt{Q^2 + U^2 + V^2} = DOP \cdot I$$

$$I_{unpol} = I - \sqrt{Q^2 + U^2 + V^2} = (1 - DOP) \cdot I$$

$$DOP = \frac{\sqrt{Q^2 + U^2 + V^2}}{I} = I_{pol} / I$$

$$\tan(2\psi) = \frac{U}{Q}$$

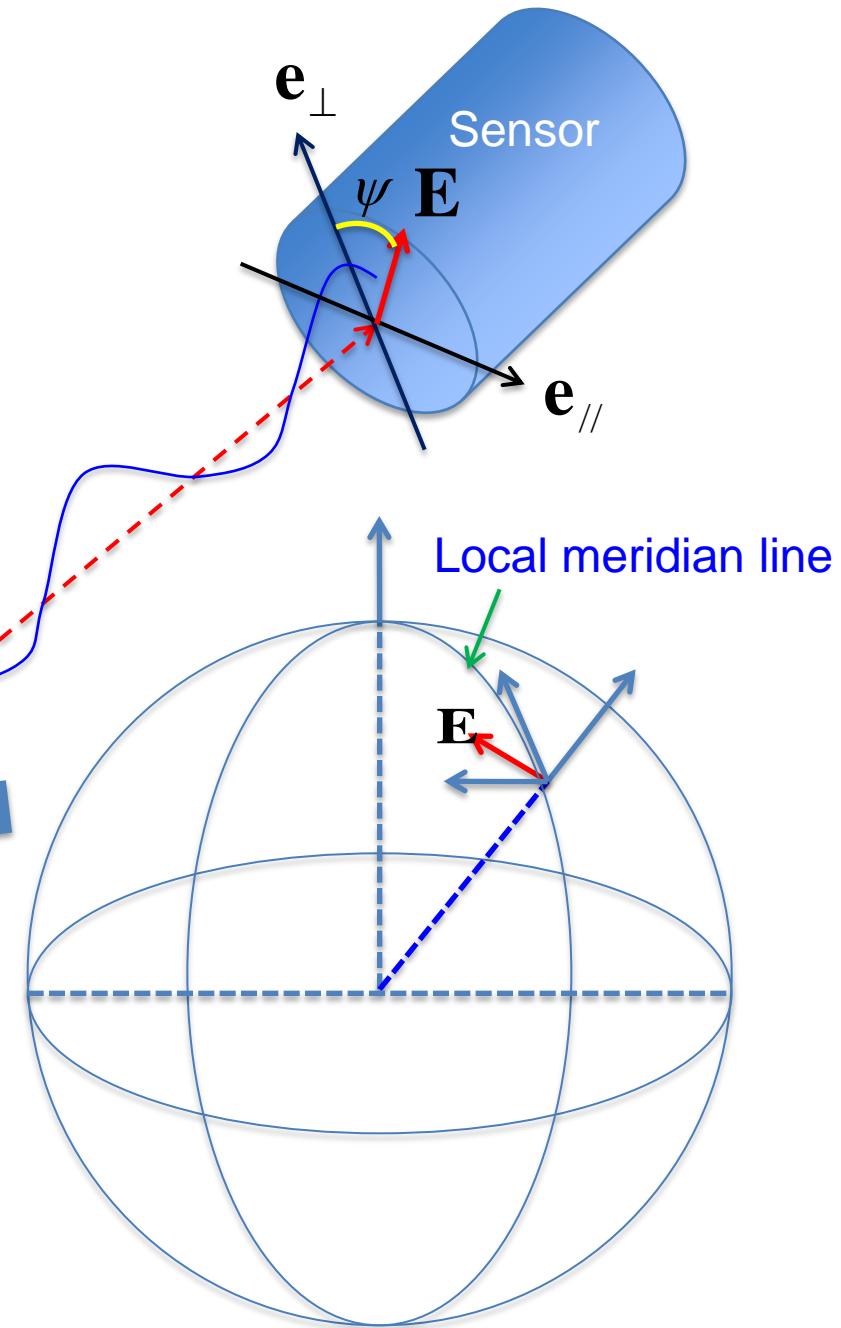


$$I = E_{\perp}E_{\perp}^* + E_{\parallel}E_{\parallel}^*$$

$$Q = E_{\perp}E_{\perp}^* - E_{\parallel}E_{\parallel}^*$$

$$U = E_{\perp}E_{\parallel}^* + E_{\parallel}E_{\perp}^*$$

Angle of linear polarization (ALP) physically is the angle between e_{\perp} direction and the linearly polarized electric field vector. Zero-ALP is always along the local meridian line. 90-degree-ALP is ensured at a direction horizontal to the reflecting surface on the principal plane.



Correction of measurement errors caused by polarization

Measured Radiance:

$$I_m = G_{pol}(\psi) \cdot DOP \cdot I + G_{unpol} \cdot (1 - DOP) \cdot I$$

Corrected Radiance:

$$I = I_m / [G_{pol}(\psi) \cdot DOP + G_{unpol} \cdot (1 - DOP)]$$

where $G_{pol}(\psi)$ and G_{unpol}

are sensor's gain factors for linearly polarized radiation and unpolarized radiation, respectively, which can be measured in lab using a linearly polarized incidence over the whole concerned spectrum. The gain factor for unpolarized portion of incidence can then be derived out as

$$G_{unpol} = \frac{1}{\pi} \int_0^{\pi} G_{pol}(\psi) d\psi$$

The polarized radiative transfer model

1. Adding-Doubling radiative transfer model:

This can calculate full Stokes vector (I, Q, U, V). But for CLARREO, I, Q , and U are enough.

2. Atmospheric profiles:

Standard Atmosphere now.

3. Spectral gas absorption:

Line-by-Line and k -distribution plus ozone cross-section table.

4. Molecular scattering:

Rayleigh.

5. Particulate absorption and scattering:

Mie for water clouds (Gamma size distribution);

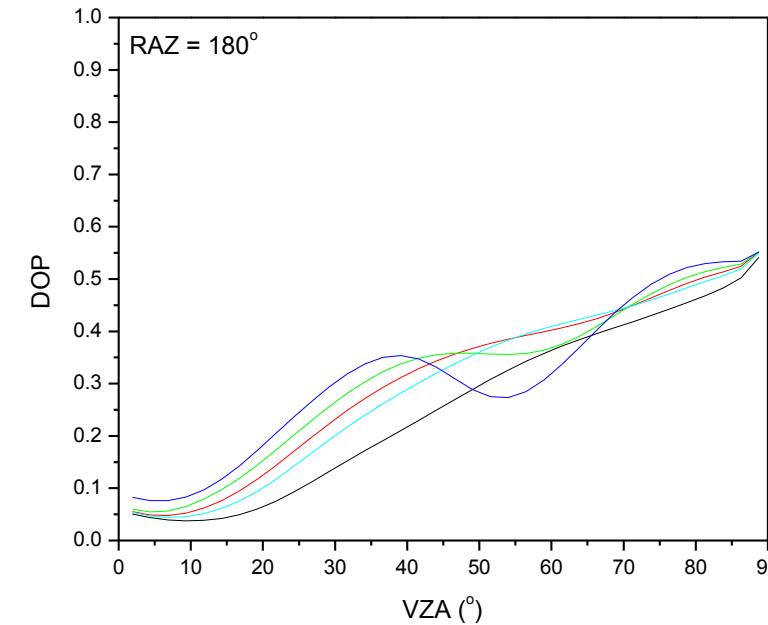
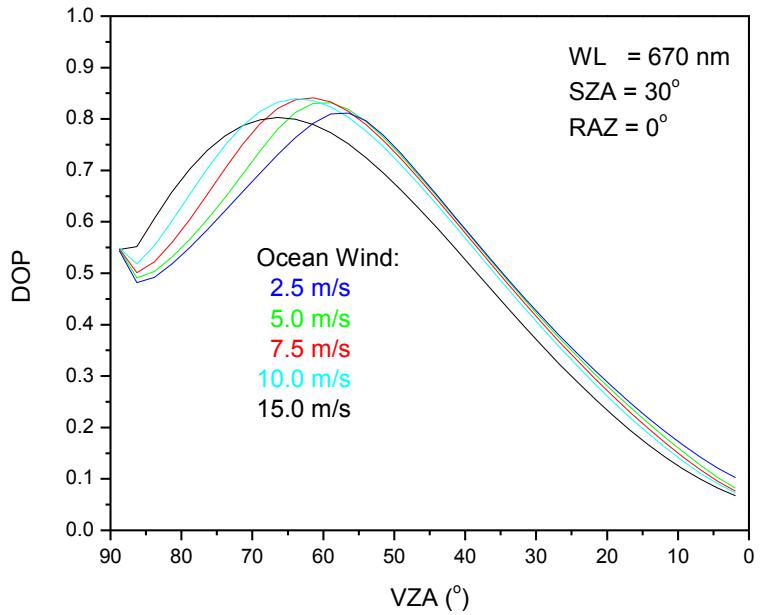
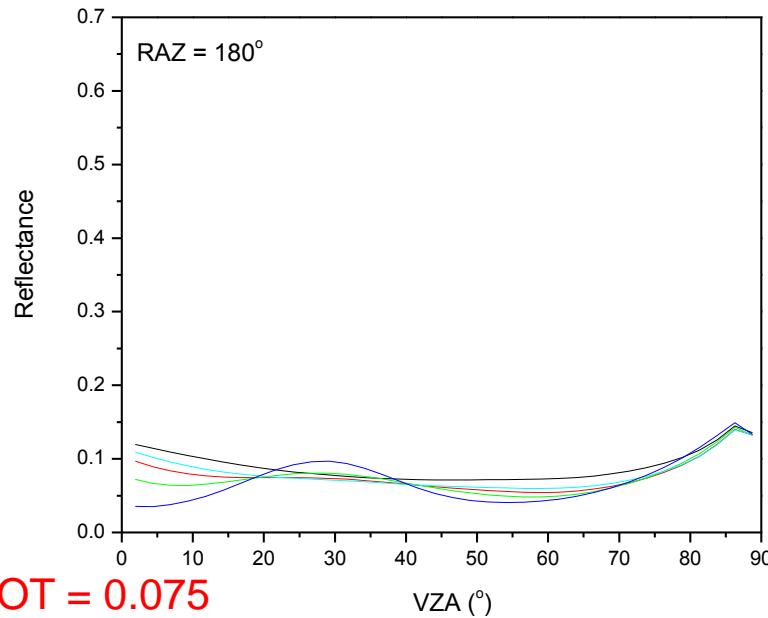
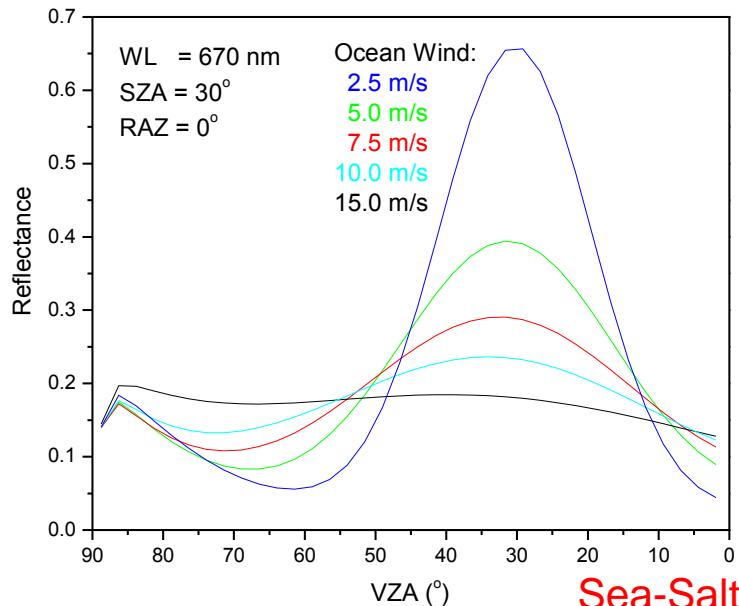
FDTD for aerosols (lognormal size distribution with fine and coarse mode);

FDTD plus GOM for ice clouds (lognormal or measured size distributions).

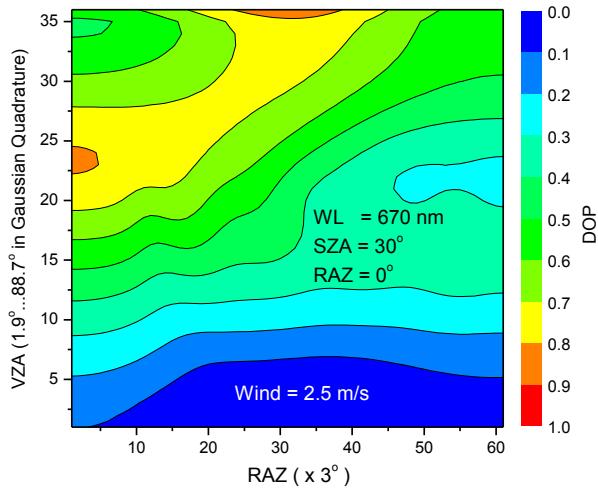
6. Surface reflection model:

Lambert surface for land now.

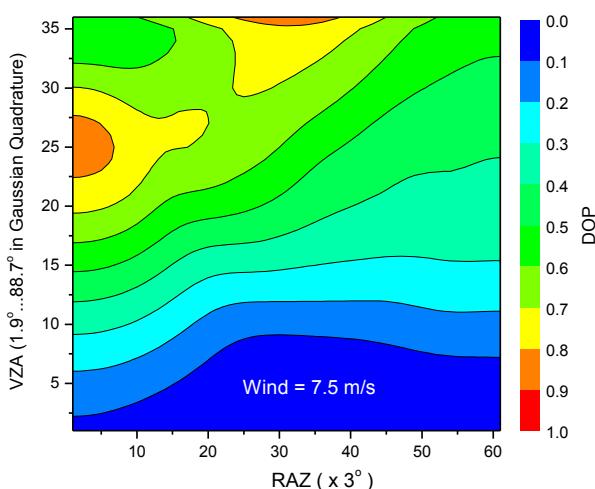
Cox & Munk + foam for wind-roughened ocean.



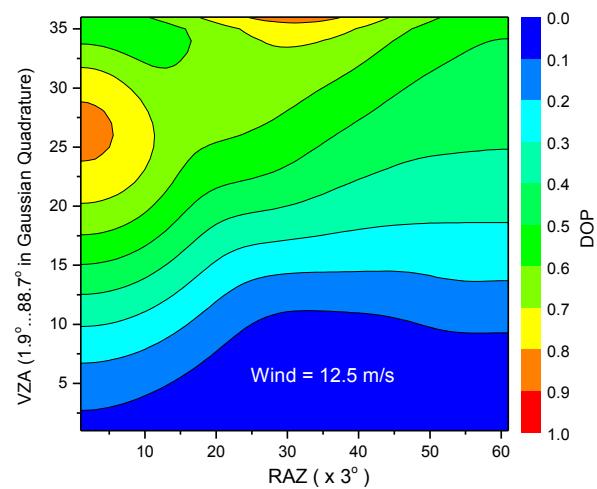
Sensitivity of clear ocean total reflectance and DOP to wind speed



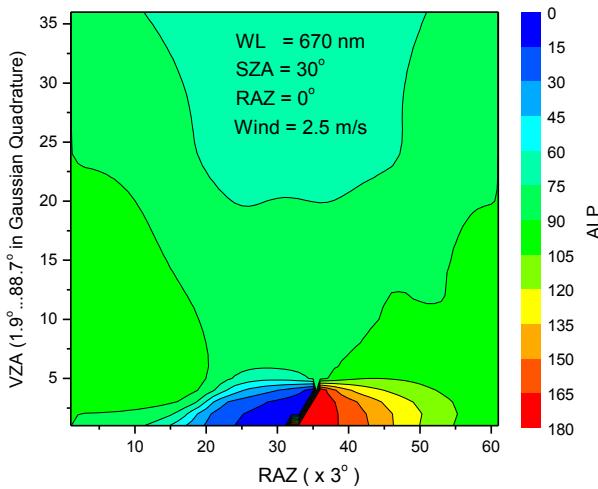
Wind = 2.5 m/s



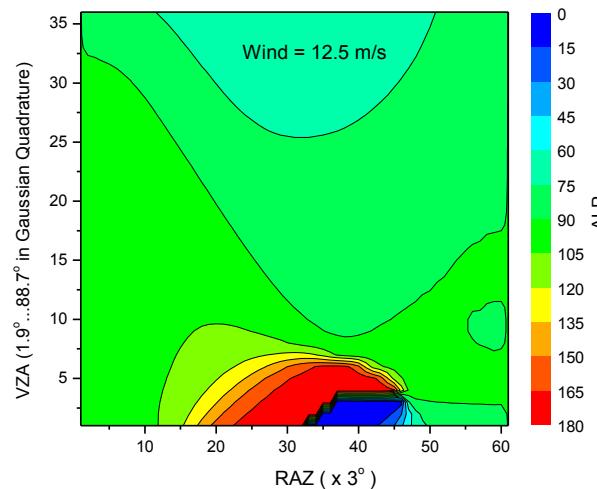
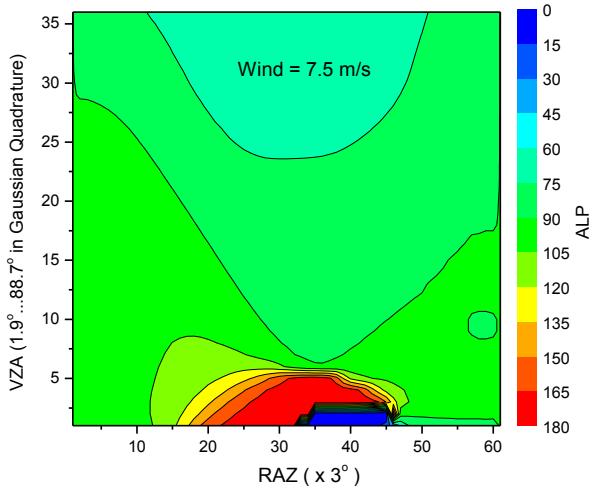
Wind = 7.5 m/s



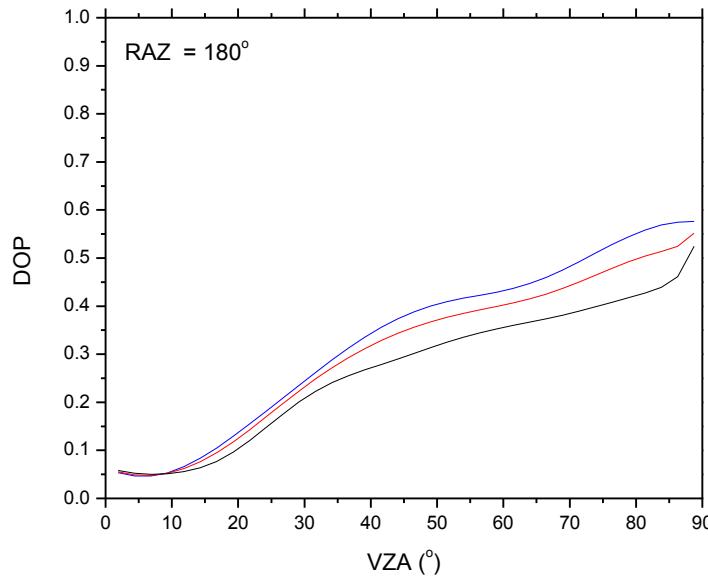
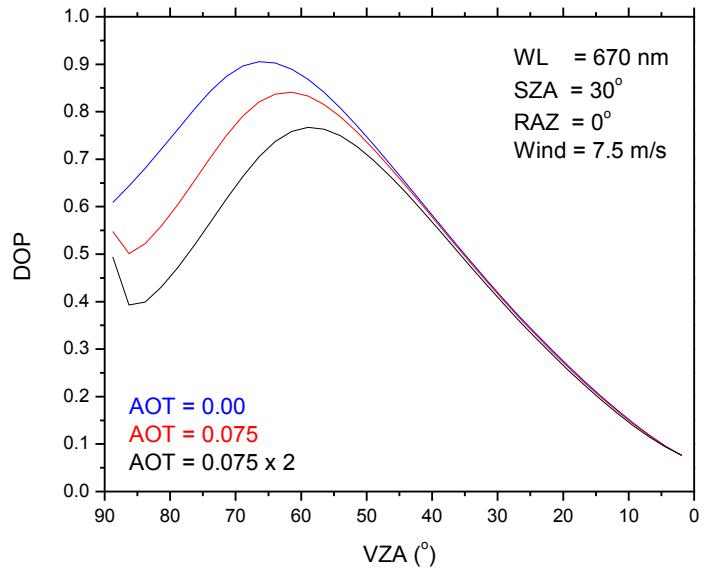
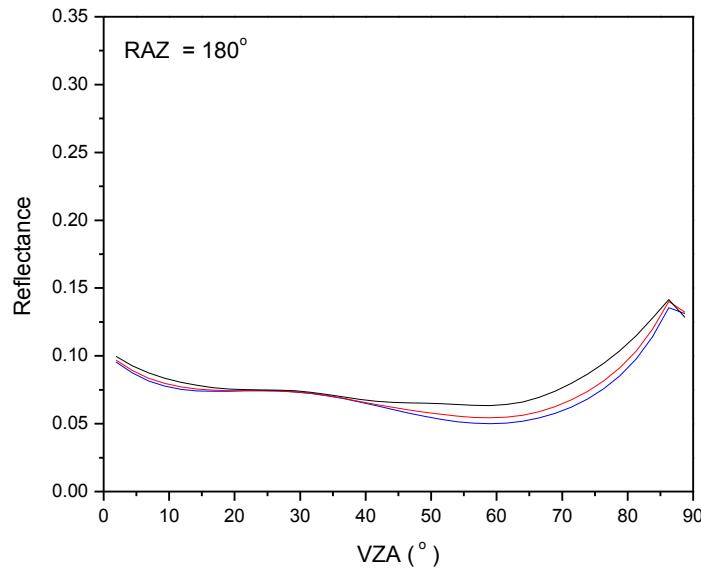
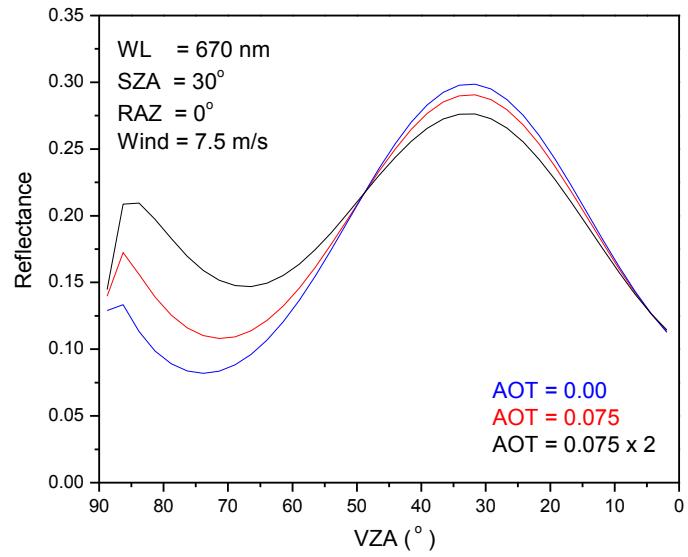
Wind = 12.5 m/s



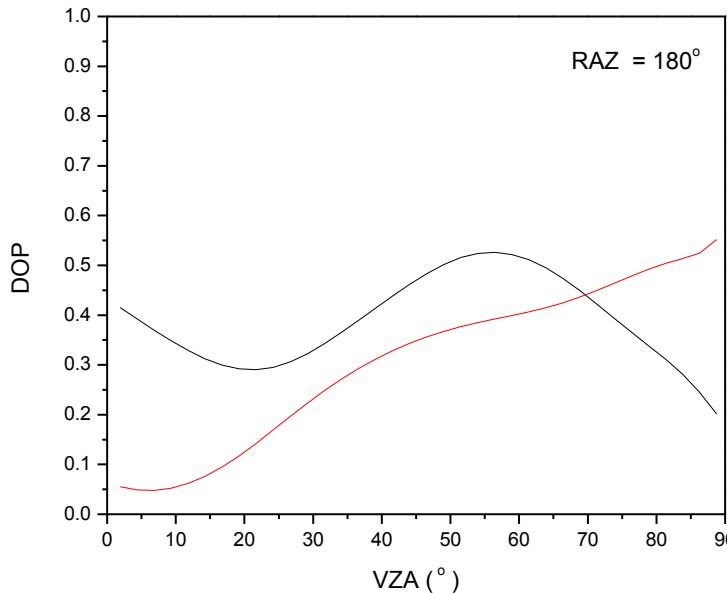
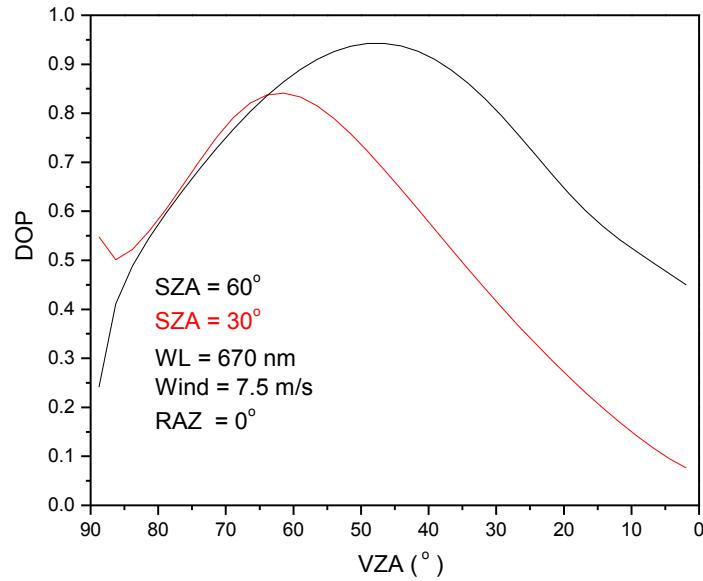
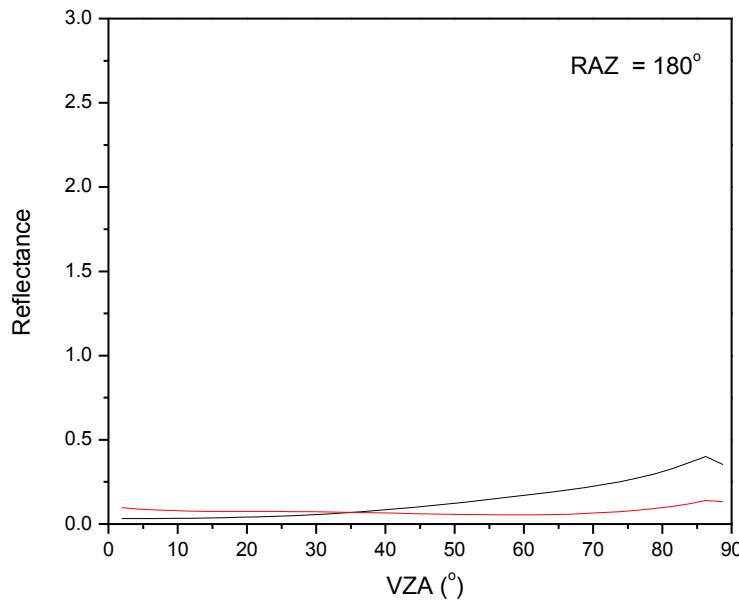
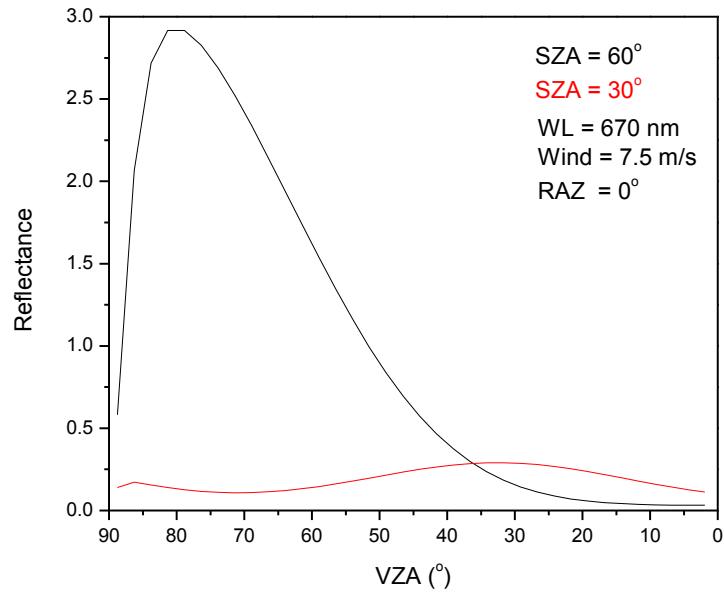
Sensitivity of clear ocean DOP and ALP to wind speed



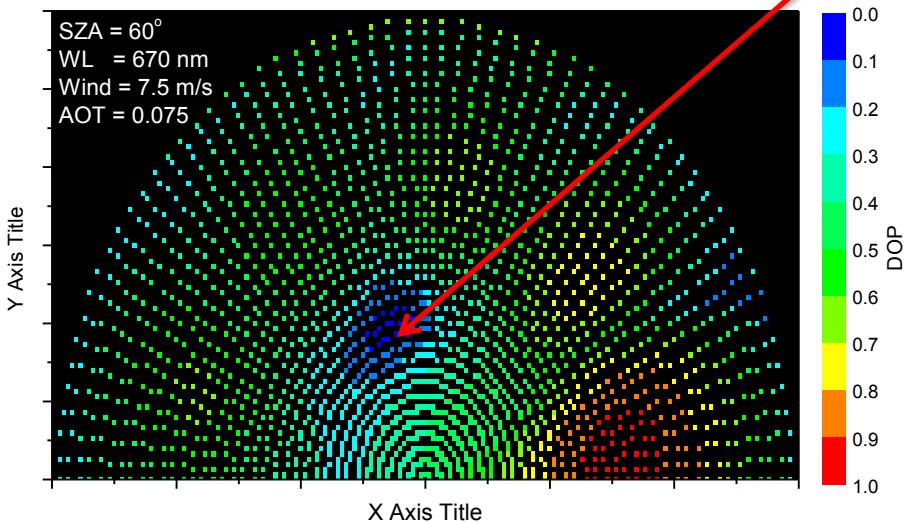
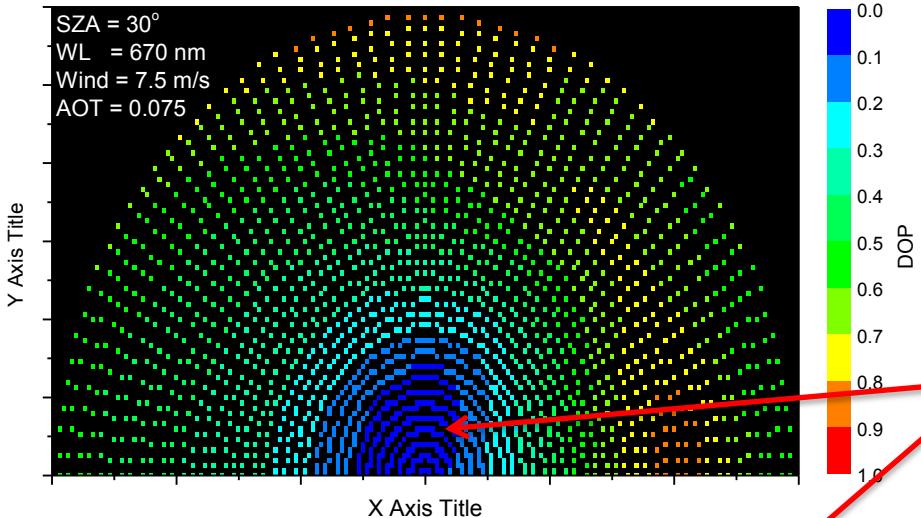
(Sea-salt AOT = 0.075)



Sensitivity of clear ocean DOP and ALP to aerosol

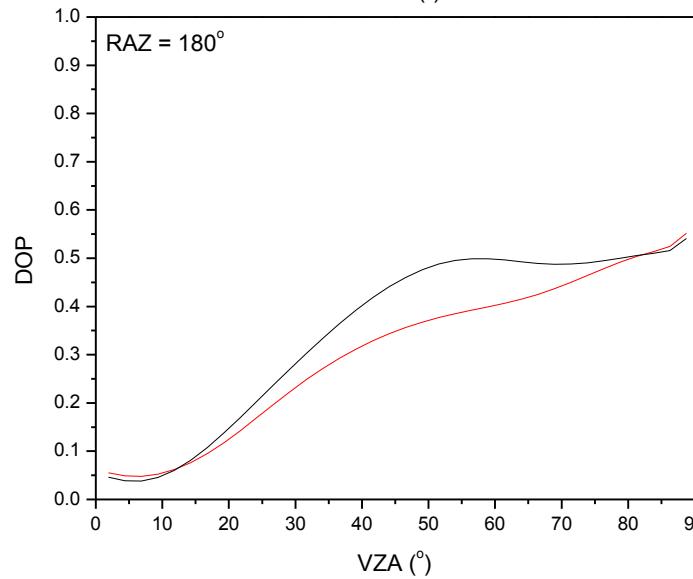
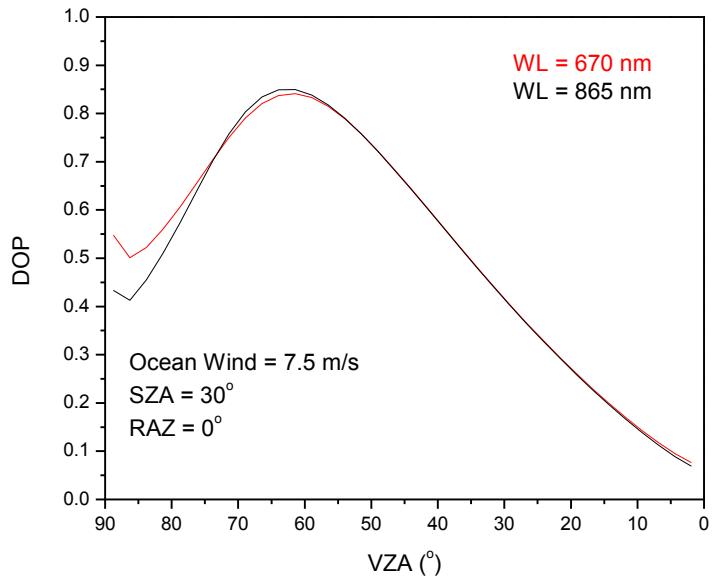
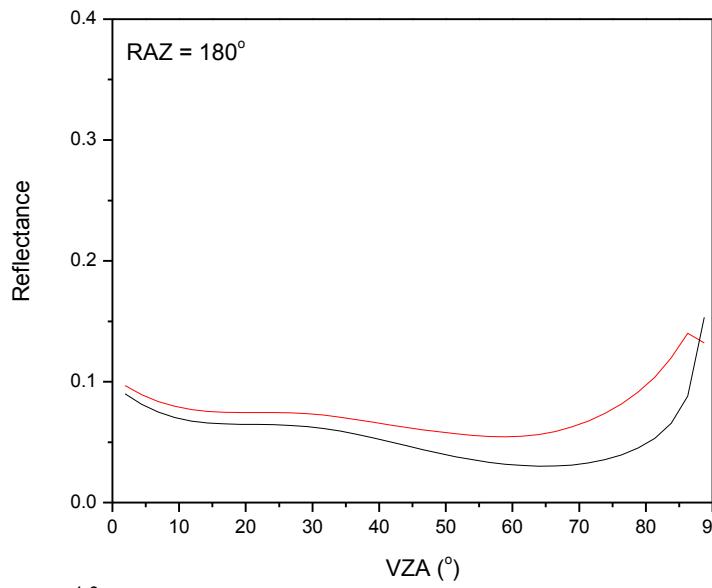
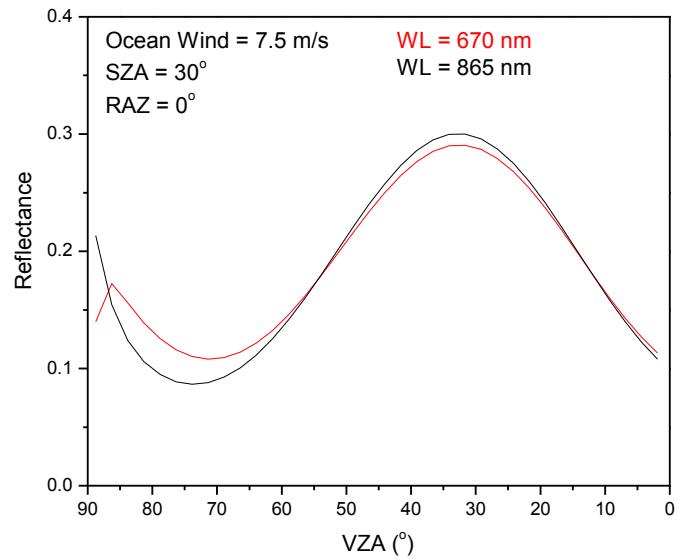


Sensitivity of clear ocean total reflectance and DOP to solar zenith angle

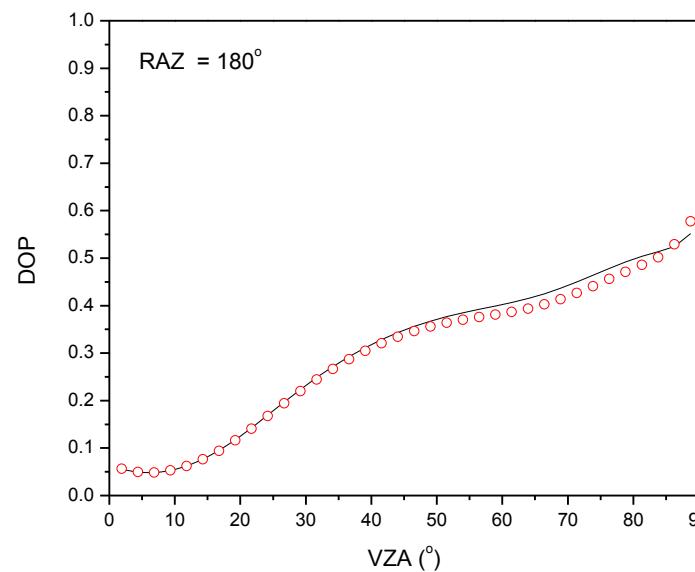
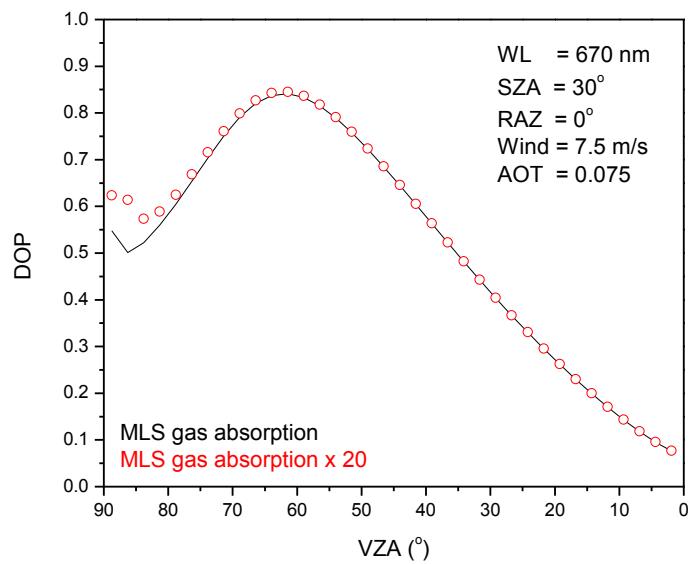
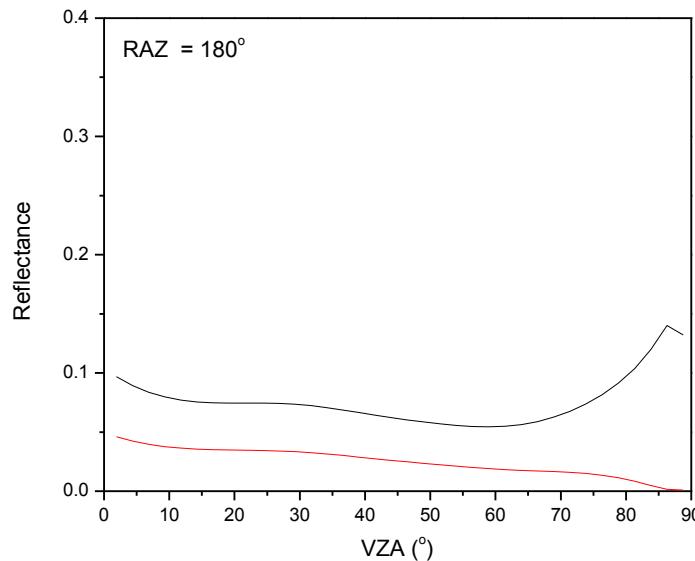
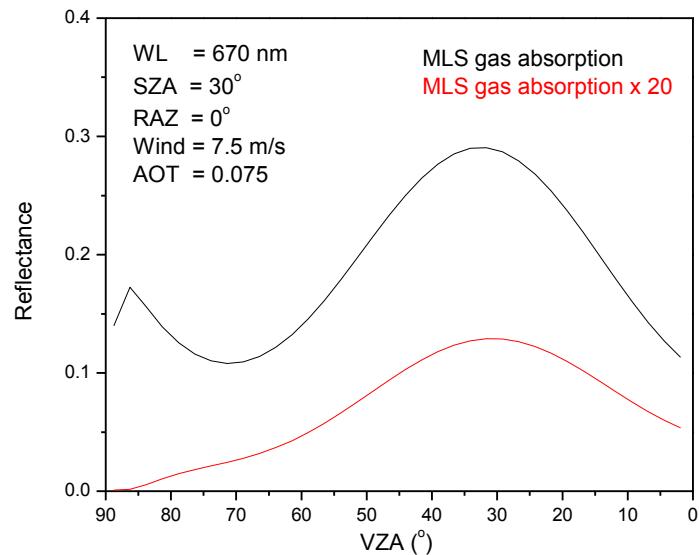


Radiance in the blue angle range has ~0 degree of polarization. These neutral-polarization VZAs are suitable for calibrating polarized sensors such as the instruments on PARASOL or Glory.

Sensitivity of clear ocean DOP to solar zenith angle



Sensitivity of clear ocean total reflectance and DOP to wavelength



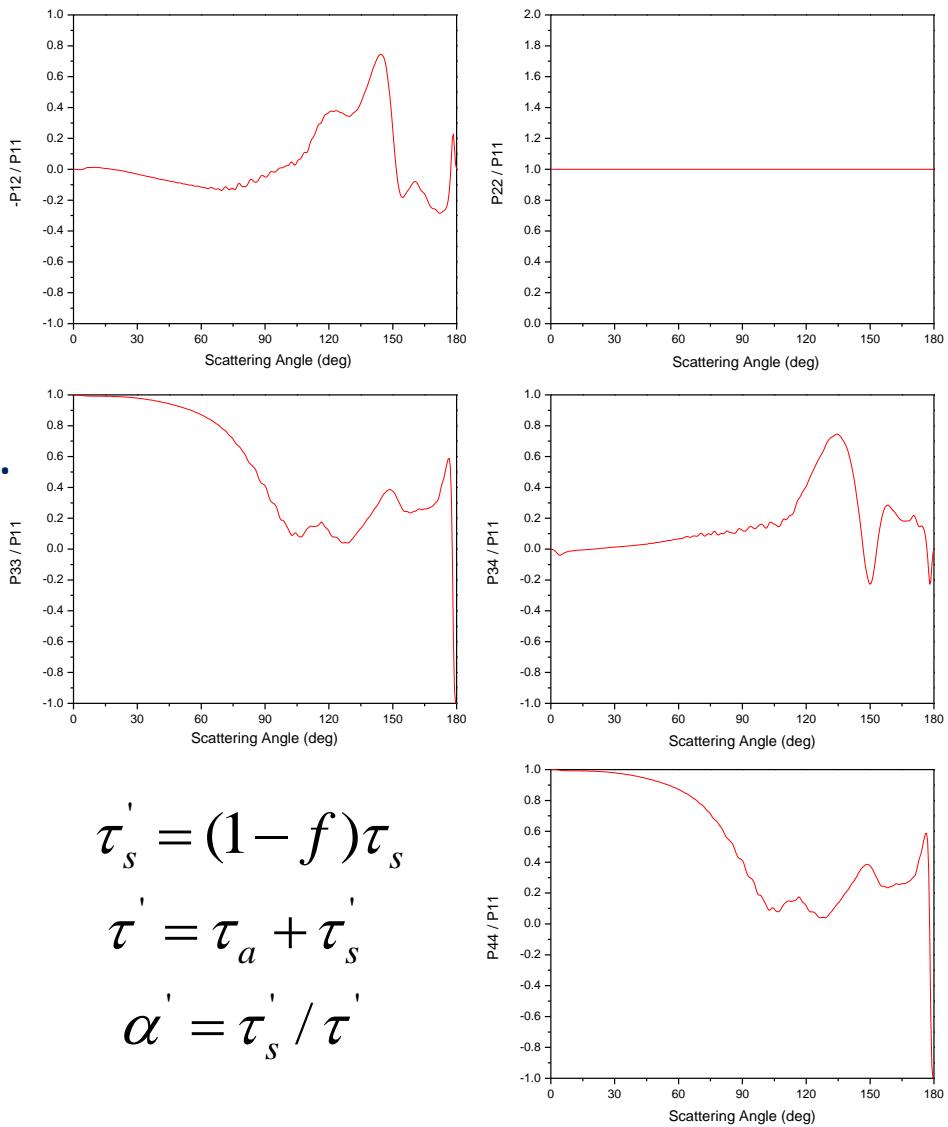
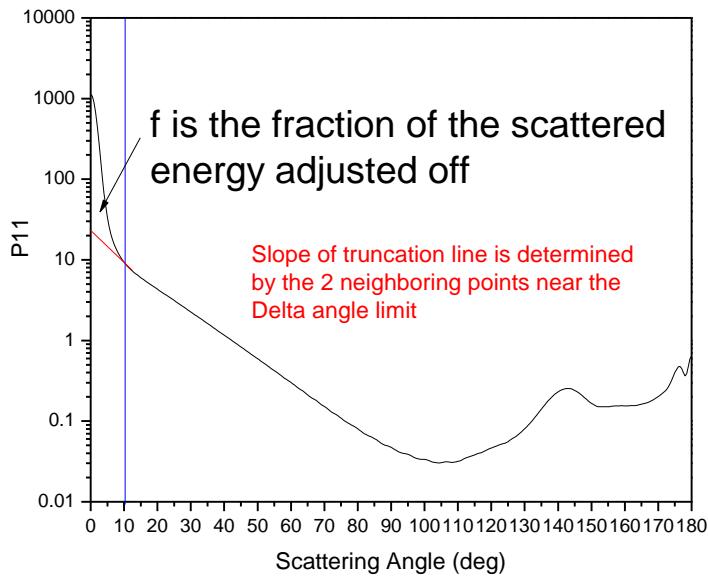
Atmospheric gas absorption does NOT affect DOP

Modeling polarized radiation for clouds

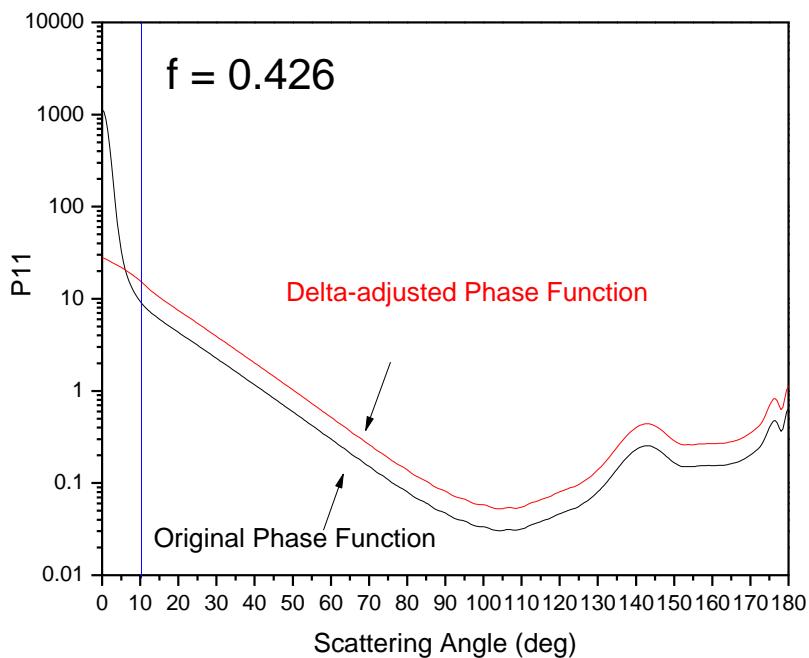
Delta-adjustment to cloud optical properties

Delta-adjustment to cloud phase functions is done to avoid too many Legendre terms and streams in the RT calculation.

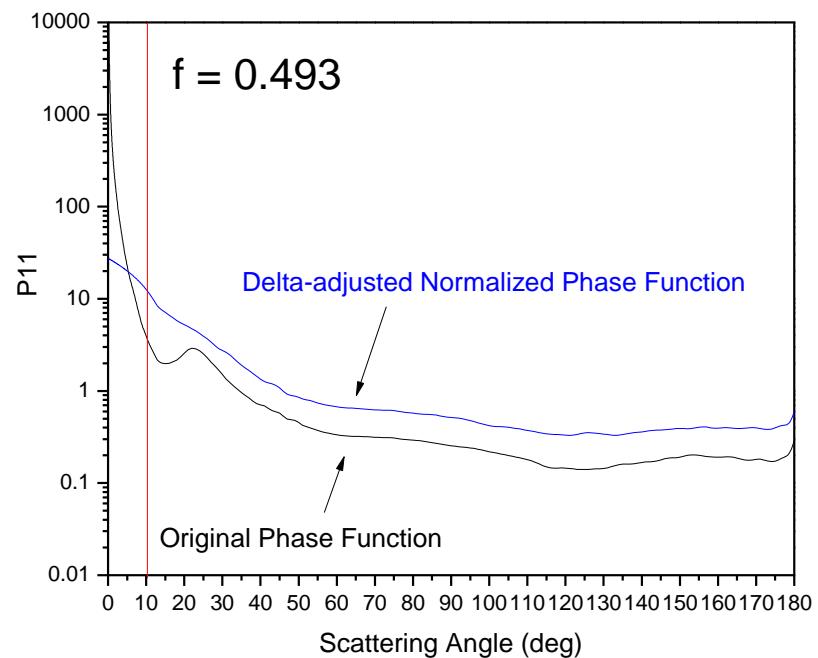
Other elements of phase matrix are adjusted with conserving their ratio values to the phase function.



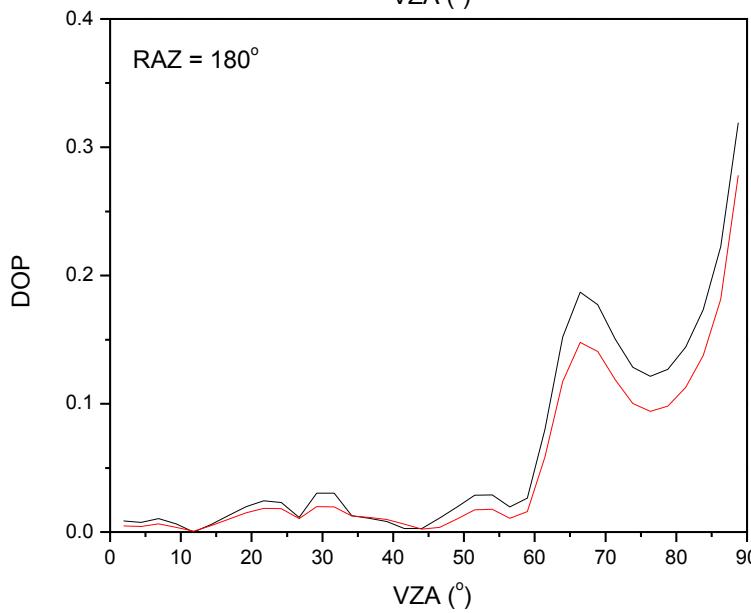
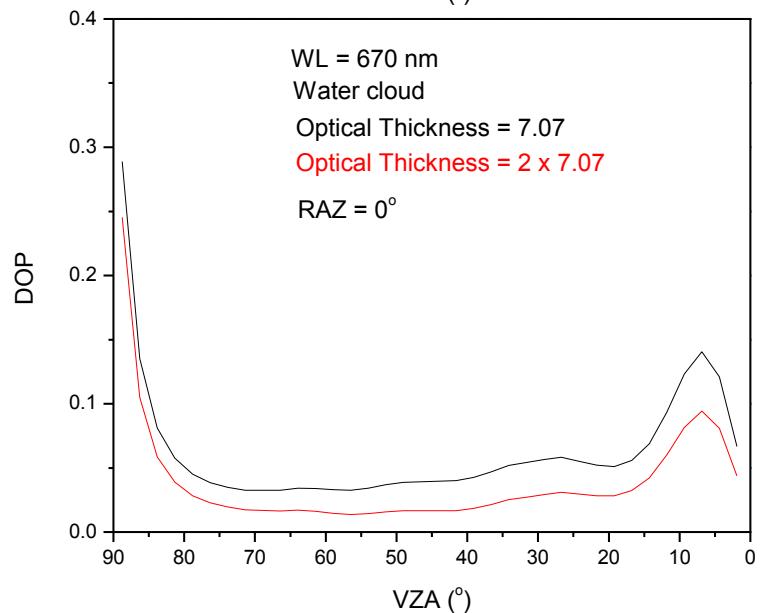
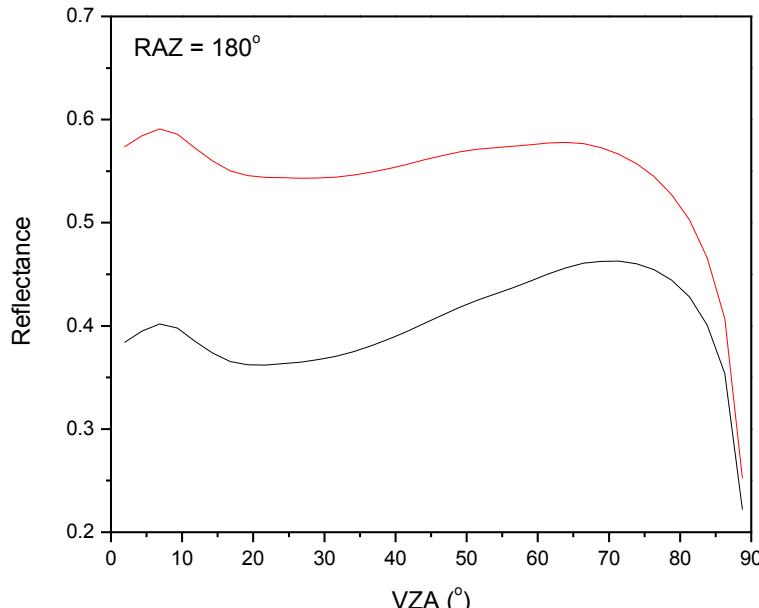
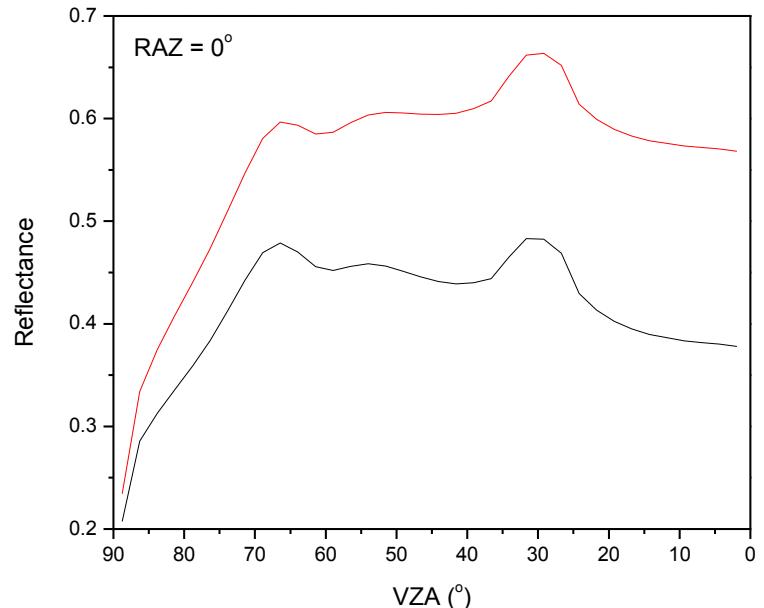
Water Cloud



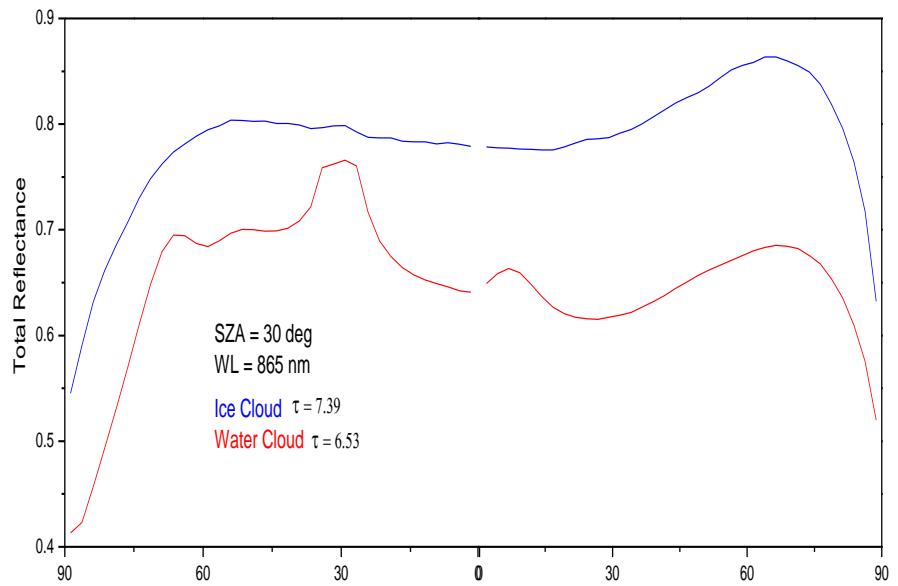
Ice Cloud



Delta-adjusted phase functions of water and ice clouds used in this calculation

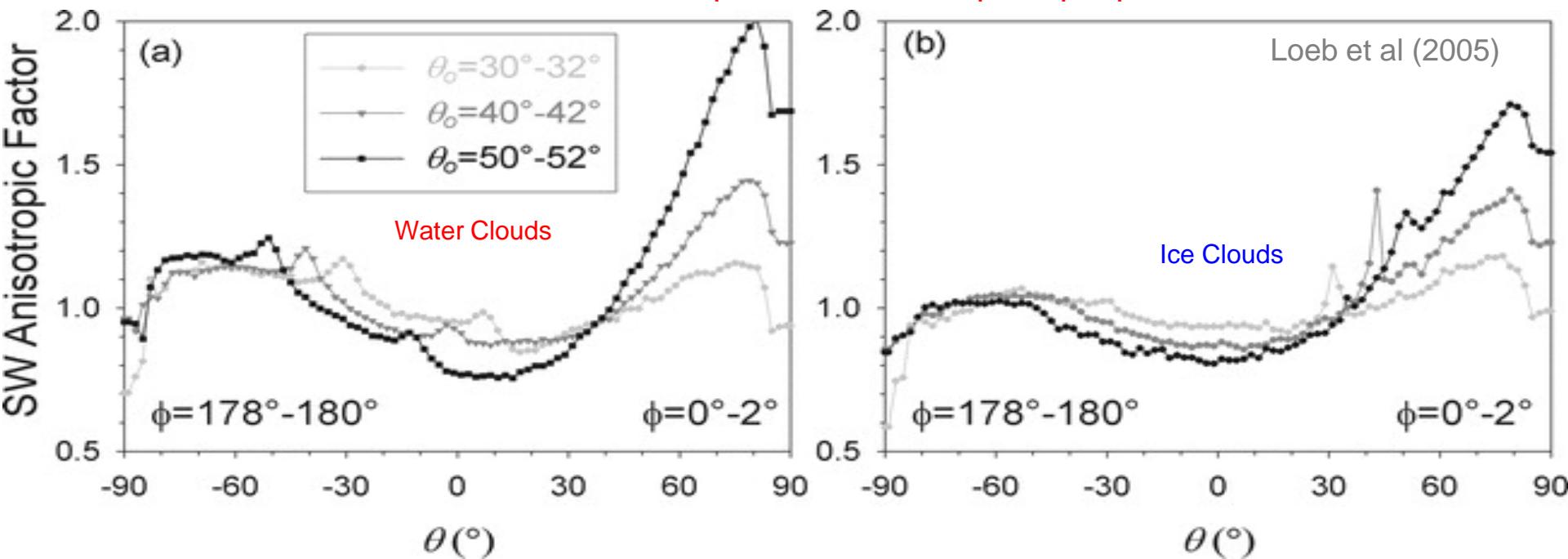


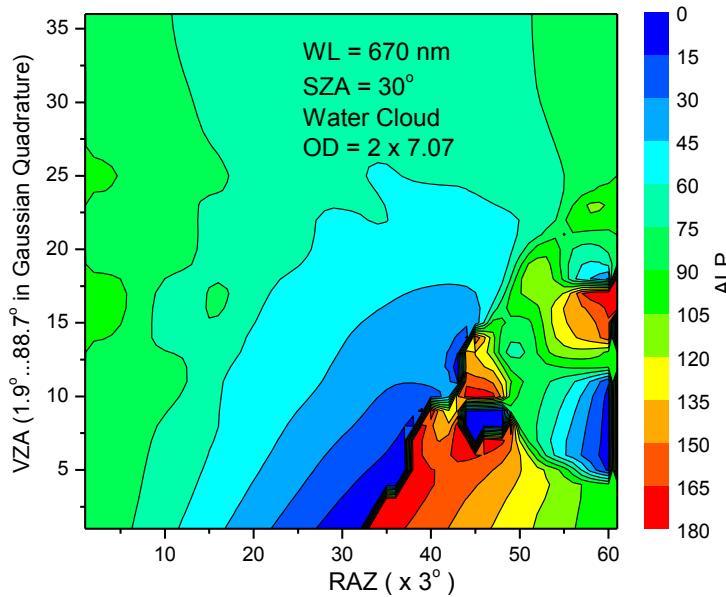
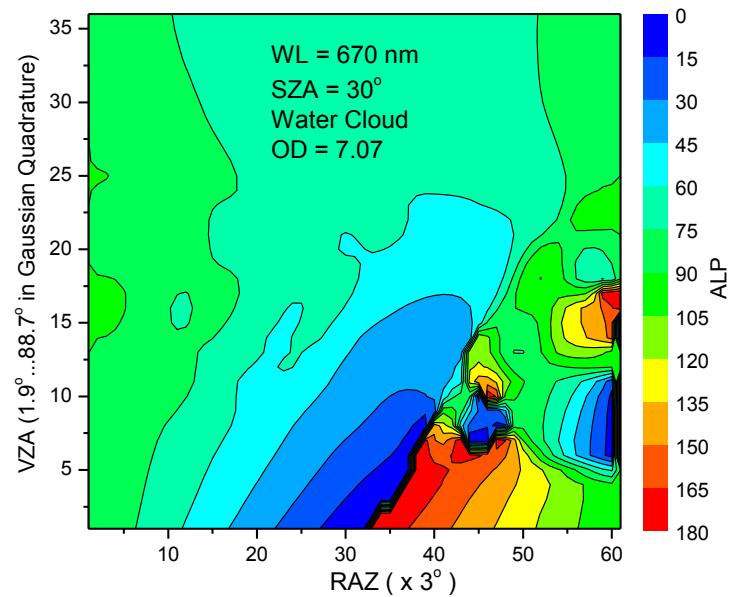
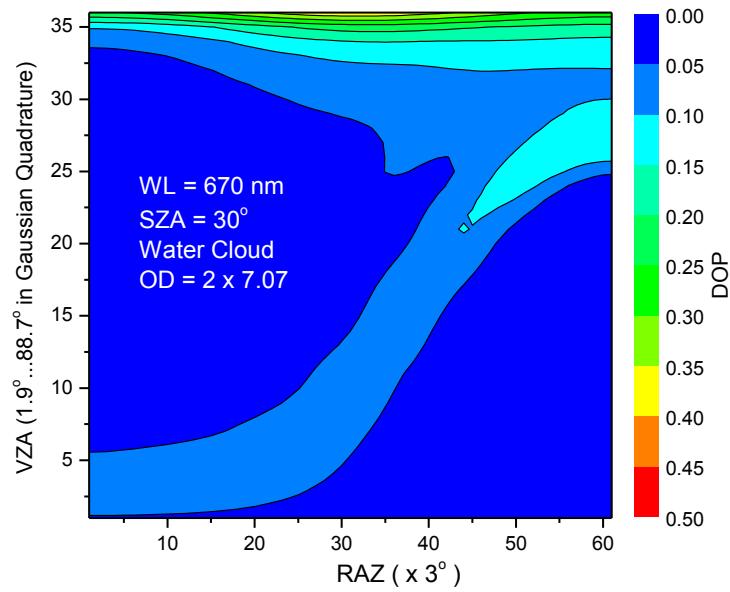
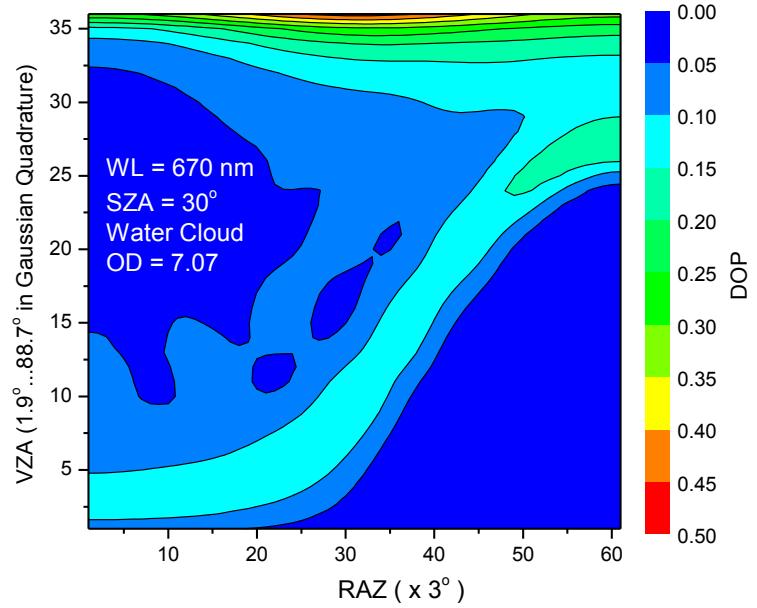
Sensitivity of TOA reflectance and DOP to water cloud optical thickness



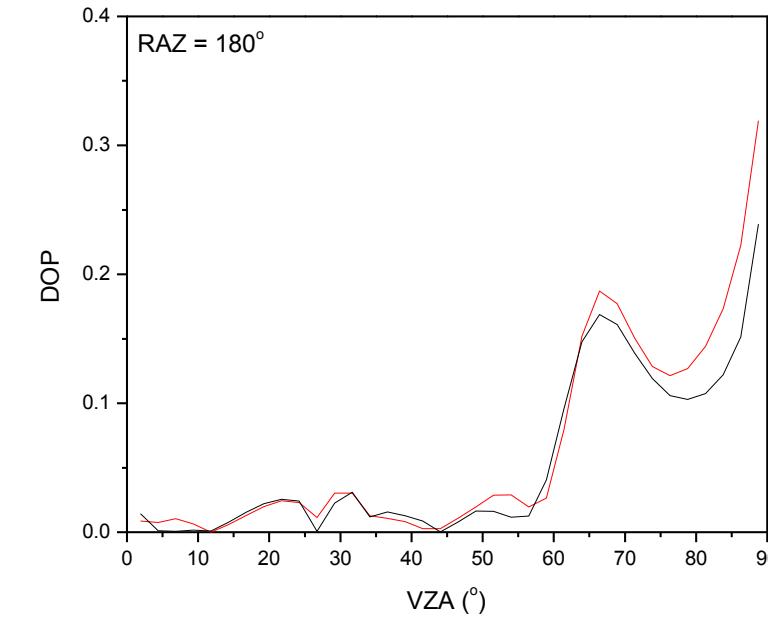
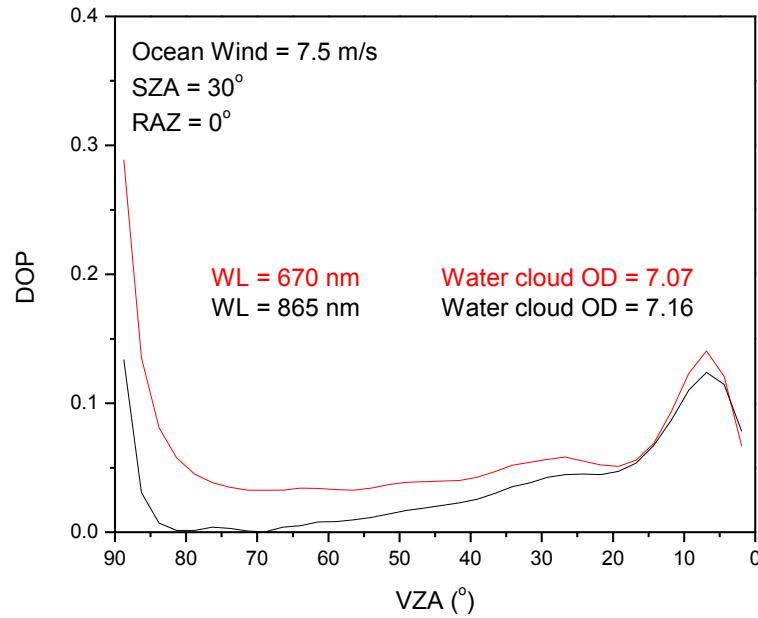
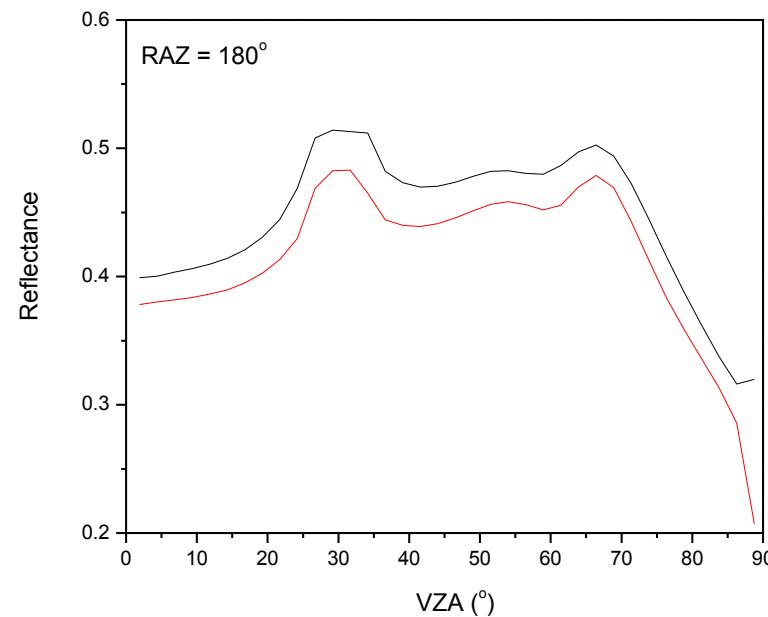
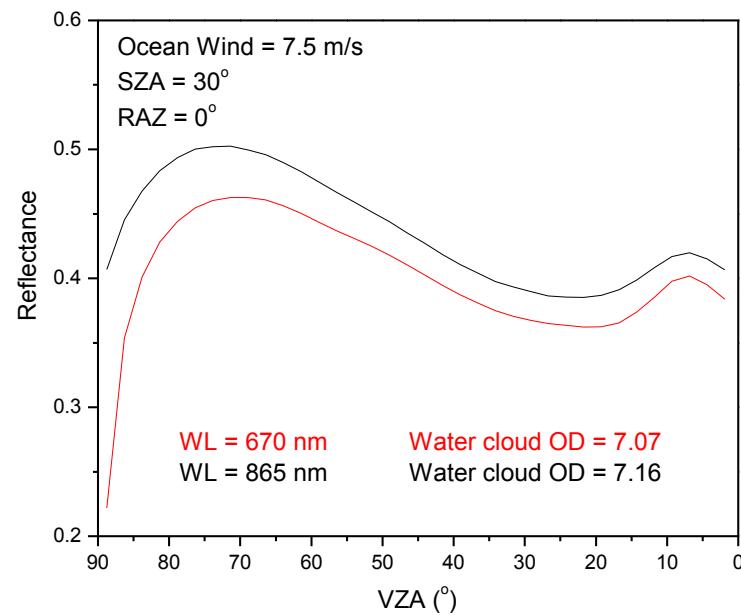
Model results have excellent agreement with CERES data in total radiance angular anisotropy, except the ice cloud specular reflection, since we assume pure randomly oriented ice crystals in the model.

CERES SW anisotropic factors in the principal plane

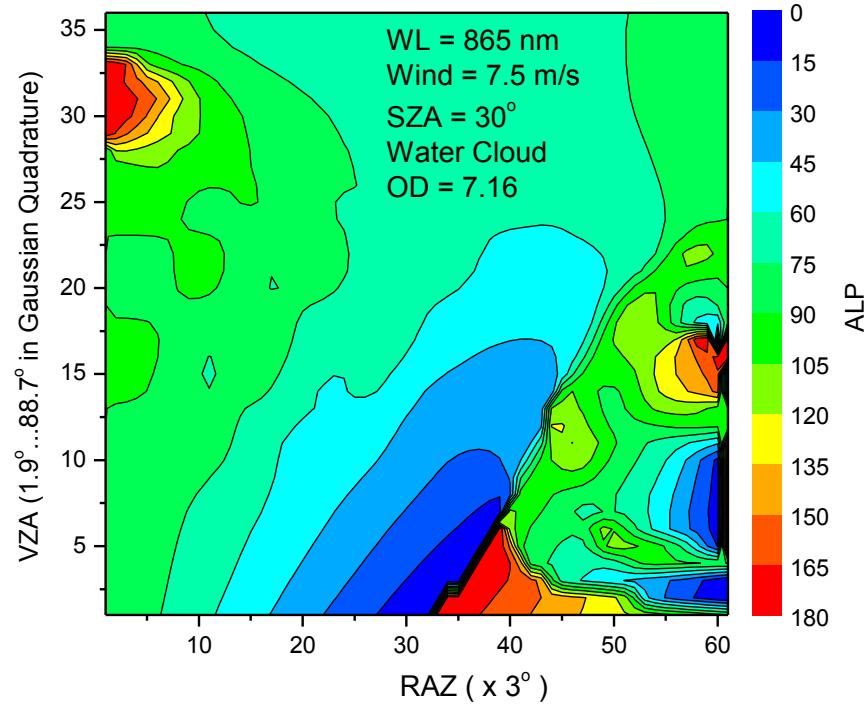
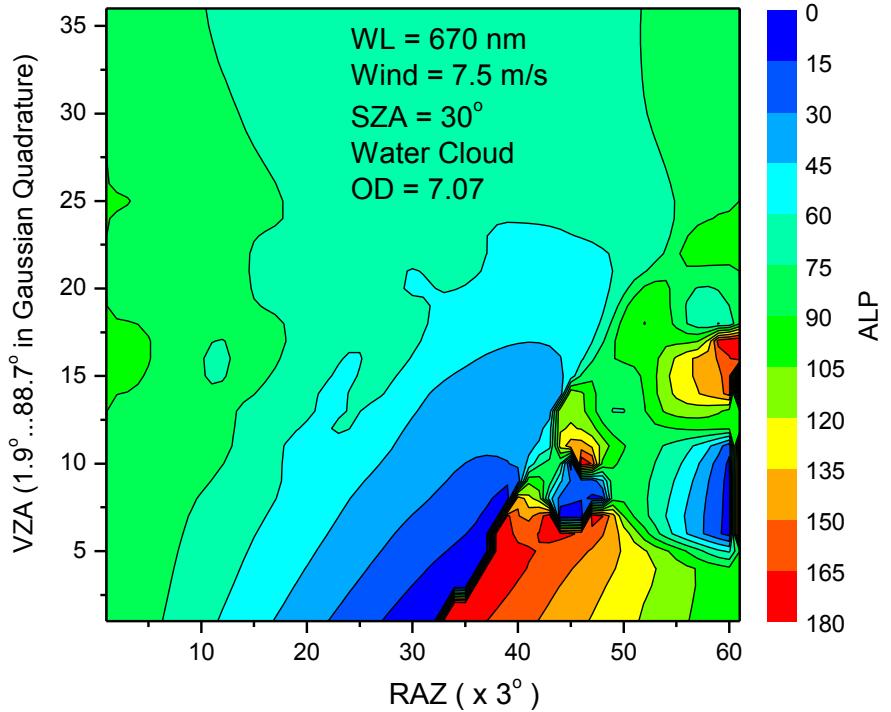




Sensitivity of DOP and ALP to water cloud optical thickness



Sensitivity of water cloud total reflectance and DOP to wavelength



Sensitivity of water cloud ALP to wavelength

Summary

1. The polarized radiative transfer model for CLARREO inter-calibration applications is developed and runs well.
2. Sensitivity of polarization to wavelength, atmospheric gas absorption, ocean wind speed, aerosol, cloud optical thickness, and incidence angle are studied.
3. Further work:
 - (1) modeling land surface BPDF to replace the current Lambert land surface model;
 - (2) studying spectral response of the polarized radiance over both ocean and land;
 - (3) calculating aerosol and ice cloud single-scattering properties;
 - (4) defining CLARREO PDM algorithm and data structure.